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Biogas generation potential by anaerobic digestion for sustainable energy development in India

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ABSTRACT

The potential of biogas generation from anaerobic digestion of different waste biomass in India has been studied. Renewable energy from biomass is one of the most efficient and effective options among the various other alternative sources of energy currently available. The anaerobic digestion of biomass requires less capital investment and per unit production cost as compared to other renewable energy sources such as hydro, solar and wind. Further, renewable energy from biomass is available as a domestic resource in the rural areas, which is not subject to world price fluctuations or the supply uncertainties as of imported and conventional fuels. In India, energy demand from various sectors is increased substantially and the energy supply is not in pace with the demand which resulted in a deficit of 11,436 MW which is equivalent to 12.6% of peak demand in 2006. The total installed capacity of bioenergy generation till 2007 from solid biomass and waste to energy is about 1227 MW against a potential of 25,700 MW. The bioenergy potential from municipal solid waste, crop residue and agricultural waste, wastewater sludge, animal manure, industrial waste which includes distilleries, dairy plants, pulp and paper, poultry, slaughter houses, sugar industries is estimated. The total potential of biogas from all the above sources excluding wastewater has been estimated to be 40,734 Mm^3/year.

Contents

1. Introduction

1.1. World and India's energy requirements

Today the world consumes about 13 TW of energy and approximately 80% of that comes from burning fossil fuels. The

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Table 1
Trends of atmospheric CO_2 and average temperature [1].

Year	Atmospheric CO_2 (ppm)	Average temperature (°C)
1800	280	15
1870	280	15
1950	305	15.2
1970	325	15.2
1988	350	15.5
2000	360	15.8
2006	375	16.0
2050[a]	~550	Up to 17.2
2100[a]	Up to ~800	Up to 19.2

[a] Forecasted values.

over dependence on the fossil fuels poses risks such as depletion of fossil fuel resources and global climatic changes caused by the net increase in the atmospheric CO_2 levels [1,2]. Table 1 shows the trends regarding the CO_2 levels and the atmospheric temperature. India has an installed base of about 125 GW of electricity as of the year 2006, which includes about 66% thermal energy (85% of which is coal based) followed by hydro (26%), nuclear (3%) and renewable energy (5%). Of the current total installed renewable energy base, wind constitutes 69%, small hydro 19%, biomass 11.5%, waste to energy 0.42% and solar 0.03% [3]. Energy supply is not in pace with the energy demand which has resulted in a deficit of 11,436 MW which is equivalent to 12.6% of peak demand recorded in 2006 [3]. Primary energy demand for India from 1990 to 2005 is shown in Fig. 1 [3].

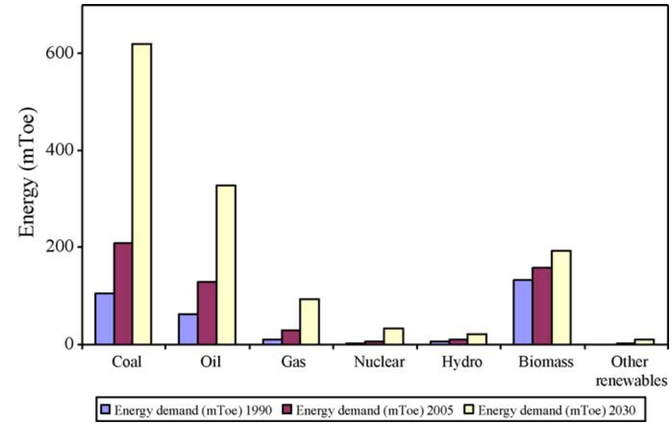

Fig. 1. Indian Primary energy demand.

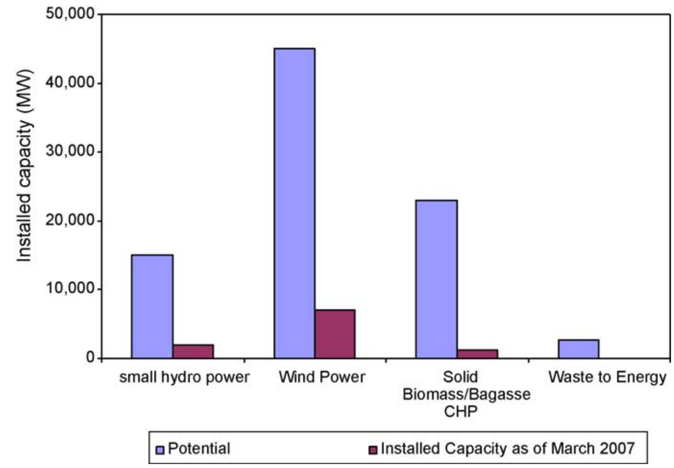

Fig. 2. Status of renewable energy potential and targets for India.

1.2. Renewable energy scenario in India

As the fossil fuel resources are limited and their demand is high, the gap can be met with the energy generation from renewable resources [4]. The need for affordable, clean and renewable energy to enhance sustainable development has been reiterated recently by the world energy council and the UN commission on sustainable development [5]. India's renewable energy resource potential is significant, with wind energy, biomass, and small hydropower representing the technologies with the largest potential [4,6–11]. Fig. 2 shows status of renewable energy potential and targets for India [3].

2. Biomass as renewable energy option

The basic concept of describing biomass as a renewable energy resource comprises the capture of solar energy and carbon from ambient CO_2 in growing biomass, which is converted to bioenergy or is used directly as a source of heat and power [12–14]. When compared to renewable energy generation from biomass with the other sources such as hydro, solar and wind, the biomass option is economical as this requires less capital investment and per unit production cost [15]. This is described in Table 2. From Fig. 2, the potential for bioenergy which includes all the forms of conversion is understood to be very high. However it is necessary to ascertain the potential of converting the biomass to biogas by anaerobic digestion so as to completely utilize the biomass and meet the energy deficit and also to control the adverse effects on the environment because of its advantages over the other bioenergy conversion processes [15]. The main objective of the present study is to assess the real potential of biogas from biomass using anaerobic digestion.

2.1. Importance of biomass

Biomass comprises all the living matter present on earth. It is derived from growing plants including algae, trees and crops or from animal manure. The biomass resources are the organic matters in which the solar energy is stored in chemical bonds. It generally consists of carbon, hydrogen, oxygen, nitrogen and sulphur in minor proportions. Some biomass also consists of significant amounts of inorganic species. Plants via photosynthesis, produce carbohydrates which form the building blocks of biomass

Table 2
Capital costs and the typical cost of generated electricity from renewable options [15].

S. no.	Source	Capital cost crores of Rs./MW	Estimated cost of generation per unit Rs./kWh
1	Small hydro power	5.00–6.00	1.50–2.50
2	Wind power	4.00–5.00	2.00–3.00
3	Biomass power	4.00	2.50–3.50
4	Bagasse cogeneration	3.50	2.50–3.00
5	Biomass gasifier	1.94	2.50–3.50
6	Solar photovoltaic	26.50	15.00–20.00
7	Energy from waste	2.50–10.00	2.50–7.50

Table 3
Comparison of direct burning of dung and its use as biogas [11].

Parameters	Direct burning	Biogas
Gross energy	10,460 kcal	4713 kcal
Device efficiency	10%	55%
Useful energy	1046 kcal	2592 kcal
Manure	None	10 kg of air dried

[10,13]. Biomass has always been a major source of energy for mankind from ancient times. Presently, it contributes around 10–14% of the world's energy supply [10] and accounts for 80% of rural energy demand [5]. Traditionally, biomass had been utilized through direct combustion. Burning biomass produces pollutants including dust and the acid rain gases such as sulphur dioxide and nitrogen oxides but the sulphur dioxide produced is 90% less than that is produced by burning coal. The quantities of atmospheric pollutants produced are insignificant compared to other pollution sources. Biomass usage as a source of energy is of interest because it is renewable, potentially sustainable and relatively environmentally friendly source of energy [13,16,17]. The energy obtained from biomass will augment the energy obtained from other resources and helps in the extension of the lifetime of the conventional resources of energy production. Biomass can be converted into a variety of energy forms such as heat, steam, electricity, hydrogen, methane, ethanol and methanol [17].

In India, over 80% of the total energy consumed in rural areas comes from biomass fuels such as fire wood, crop residues and live stock dung [5]. With the on going destruction of forests due to overuse and degradation, scarcity of wood has become increasingly common in India. Since live stock such as cattle, buffalo, sheep and goat are common in Indian rural areas, animal dung is the most easily available and abundant biomass for fuel and the burning of the dung is common in rural areas. Cow dung has been used as both fertilizer and fuel in many countries around the world for centuries. The advantages of using the dung for digestion when compared to direct burning is given in the following Table 3 [11]. The biogas obtained from digestion of biomass is successfully utilized in some parts of India and this has resulted in enhancing the local ecology and relieving economic stress in rural communities [5,18]. The conversion of biomass into energy also results in significant reduction in volumes and the digested sludge can be used as a fertilizer for the agricultural fields. The another major advantage for using biomass as a source for renewable energy is being available as a domestic resource in the rural areas, which is not subject to world price fluctuations or the supply uncertainties as of imported and conventional fuels.

2.2. Biomass to bioenergy options

Biomass can be converted into various bioenergy forms such as ethanol, butanol, methane, hydrogen, electricity, biodiesel through various processes [19,20]. Some options are found to be very successful and efficient where as the other options are still facing technical challenges such as low energy net yield, water pollution, conversion efficiency, capital investment [1]. The various popular options for biomass conversion to bioenergy along with their problems and advantages are listed in Table 4. Anaerobic digestion is selected for the current study because of its advantages over the other processes.

2.3. Principles of anaerobic digestion

The anaerobic digestion process is considered to be a minimum of two stage biological reactions, involving at least two different groups of microorganisms, acid-forming bacteria (saprophytic) and the methane forming bacteria. The acid phase is generally considered to include the conversion of complex organic compounds into simpler organic compounds and finally into the organic acids, principally acetic acid by acid-forming bacteria [21–25]. The methane formation step is where the major waste stabilization occurs. A typical flow sheet for the anaerobic process is shown in Fig. 3 [26].

There are four basic reactor configurations that have been used for the design of anaerobic unit process namely single stage unmixed, two stage mixed primary, anaerobic contact process with sludge recycle and anaerobic filter. The first two types are generally used for the digestion of solid wastes and wastewater sludge. High rate digestion systems are designed usually as two

Table 4
Leading options for biomass energy [1].

Biomass energy option	Problems	Advantages
Food crop (e.g., corn or sugar cane) to ethanol (C_2H_5OH).	Very low net energy yield, competition with food crops, water pollution, inherently low yield per unit area	Strong political lobbies; can be used with gasoline
Food crop (e.g., corn or sugar cane) to butanol (C_4H_9OH)	Low net energy yield, competition with food crops, water pollution, inherently low yield per unit area	Better net energy yield than ethanol
Cellulosics (e.g., switchgrass or *Miscanthus*) to ethanol or butanol	Unproven at large scale; low net energy yield	Higher yield per unit area, less severe competition with food crops, and less water pollution than with food crops.
Complex biomass (e.g., animal waste) to methane (CH_4)	Conversion efficiency is not yet high enough; unit cost is higher than from natural-gas deposits today	Mature technology; can use residues and wastes, turning a pollution problem into an energy resource; CH_4 infrastructure is in place
Complex biomass (e.g., animal waste) to hydrogen (H_2)	Technology is immature; conversion efficiency today is very low	Can use residues and wastes, turning a pollution problem into an energy resource; H_2 can be used in fuel cells
Complex biomass (e.g., animal waste) to electricity (e^-) via the microbial fuel cell (MFC)	Technology is nascent; conversion efficiency is not established	Electricity infrastructure is in place; an MFC is a combustionless, pollution free fuel-cell technology that uses renewable organic fuel directly
Plants (e.g., Jatropha, soy beans, or sunflowers) to biodiesel (mainly C-16 and C-18 aliphatics)	Technology is immature; yield per unit area is inherently low; competes with food crops	Biodiesel is a high-density fuel that is an ideal substitute for petroleum
Phototrophic microorganisms (algae or cyanobacteria) to biodiesel	Technology is at an early stage; may require a significant capital investment	Biodiesel is a high-density fuel that substitutes ideally for petroleum; possible to have very high yield per unit area, allowing TW output; does not compete with food crops

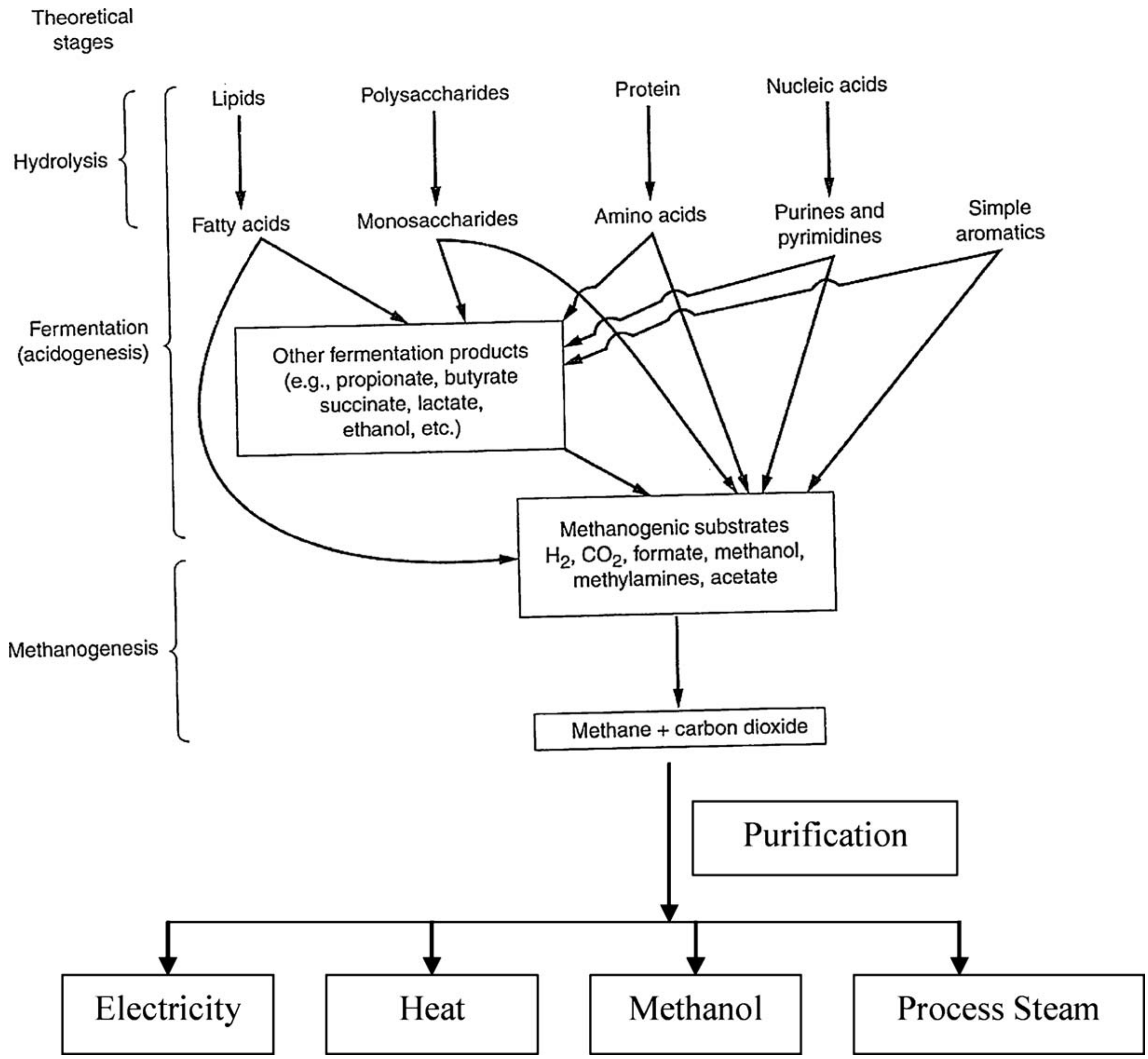

Fig. 3. A typical flow sheet for anaerobic digestion process.

stage systems. The stability of the anaerobic process and the rate of gas production are both dependant upon organic loading rates [21,23]. The principal gases produced during the anaerobic digestion process are methane and carbon dioxide. Small amounts of hydrogen sulphide is also produced which may be noticeable in terms of the odour characteristics of the digester gas. Typical details about the biogas are given in Table 5 [16].

2.4. Biomass resources in India

The biomass resources in India is available in plenty in the form of municipal solid waste, crop residue, agricultural waste, waste-water sludge from wastewater treatment plants, animal manure and industrial waste. Hence the main focus of this paper is to analyze the energy potential of biomass resources in the form of residues and wastes for anaerobic digestion with the following objectives.

a. To estimate the total biomass resources such as municipal solid waste, crop residue, animal manure, sewage from urban areas and industrial waste.
b. To estimate the biogas potential from the different biomass resources such as municipal solid waste, crop residue, animal manure, sewage from urban areas and industrial waste.

Table 5
Typical details about biogas [16].

Composition	55–70% methane, 30–45% carbon dioxide, traces of other gases
Energy content	6.0–6.5 kW m^{-3}
Fuel equivalent	0.6–0.65 L oil/m^3 biogas
Explosion limits	6–12% biogas in air
Ignition temperature	650–750 °C
Critical pressure	75–89 bar
Critical temperature	−82.5 °C
Normal density	1.2 kg m^{-3}
Odour	Bad eggs (the smell of hydrogen sulphide)

2.4.1. Municipal solid waste

Municipal solid waste with the major fractions as paper, cardboard, putrescibles is a potential feedstock for anaerobic digestion [27–31]. Municipal solid waste contains both organic and inorganic fractions. However the organic fractions are digested. The physical and chemical characteristics of the municipal solid waste in India are given in Tables 6 and 7 [32]. The compostable matter in the MSW is ranging form 30.84% in very big cities whose population is above 5 million to 56.57% in cities having population between 2.0 and 5.0 million. On average the compostable matter percentage is 42.194%, which is a very good

Table 6
Physical characteristics of MSW in Indian cities population wise [32].

Population in range (in million)	No of cities surveyed	Compostable matter	Inert material
0.1–0.5	12	44.57	43.59
0.5–1.0	15	40.04	48.38
1.0–2.0	9	38.95	44.73
2.0–5.0	3	56.57	40.07
5.0 and above	4	30.84	53.9

amount for anaerobic digestion. The C/N ratio which is very important in the conversion process is varying from 21.13 to 30.94 whereas the calorific values are varying from 800.70 to 1009.89 kcal/kg. To obtain the data regarding the quantity of MSW in the country, it was divided into 4 zones namely South, North, West and East. Each zone is further divided into four groups namely very big, big, medium and small cities. From the data it is observed that the north zone is producing maximum waste when compared to the other zones. The total waste produced is 97,173 t/day; Table 8 [33]. Studies had been carried on anaerobic digestion of municipal solid waste [32] and it is found that biogas can be generated at a rate of 95 m^3/t of solid waste. The biogas potential for the MSW is estimated as 9.23 Mm^3/day.

Table 8
Solid waste generation in India [33].

Name of the zone	City classification	Solid waste (tpd)
South	Very big	10,215
	Big	490
	Medium	4325
	Small	9690
		24,720
North	Very big	13,110
	Big	4372
	Medium	4137
	Small	8063
		29,682
Western	Very big	18,479
	Big	2790
	Medium	2958
	Small	4559
		28,785
Eastern	Very big	6962
	Big	934
	Medium	1158
	Small	4931
		13,986
	Total	97,173

2.4.2. *Crop residue and agricultural waste*

India being an agrarian country, agriculture is the main source of livelihood for majority of the people. The quantity and quality of biomass obtained from the cultivation of different crops varies significantly. In India there are no specific crops grown for anaerobic digestion to produce biogas. However, there is lot of biomass available in the form of crop residue and agricultural waste which can be used for anaerobic digestion [34,35]. Generally the agricultural waste obtained from the cultivation is disposed by burning in open areas or by dumping in the field itself until next crop season. The availability of biomass is given in Table 9 [3]. The biomass generated is also used as fodder to feed animals, fire wood. The remaining biomass may be available for bioenergy generation and is estimated as 278.71 Mt/year. The biogas potential for the crop residue and agricultural waste is estimated as 45.8 Mm^3/day.

2.4.3. *Wastewater*

The wastewater generated from urban area is collected (on an average 80% of generated volume) through organized sewage collection system. The sewage obtained is treated and the sludge obtained from the treatment is then dried and used as manure. The wastewater sludge when anaerobically digested can produce biogas [28,31] and the volume of digested sludge is significantly reduced. The leachate obtained can be used as a fertilizer whereas the digested sludge can be used as manure to the agricultural fields. Anaerobic digestion of sewage sludge has been in practice in India and the biogas obtained was used for different purposes [36]. The data regarding the wastewater generation from the Indian cities is presented in the following Table 10 [33]. The total quantity of wastewater generated is estimated as 15,392 million litres per day (Mld) where as only 10,170 Mld which is about 66% collected through sewerage system and treated conventionally. The treated sewage will result in large quantity of sludge which can be converted to biogas using anaerobic digestion.

2.4.4. *Animal manure*

India harbors one of the largest bovine populations of 294 million in the world including cows, bullocks, buffalo, and calves [35]. Estimated populations of cattle and buffalo for 2010 are 224 and 97 million, respectively. Dung production largely depends on cattle population and dung yield per animal. It is very difficult to collect the dung produced by cattle as they are allowed to graze in open fields. The cattle in India are also used as draft animals for agriculture operations which includes using them for rural transportation. However the dung from the cattle can be collected only from the droppings at the cattle sheds which are generally stationed in rural areas. The total dung production is estimated as 659 Mt annually based on mean annual average dung yield of 4.5 kg/day for cattle and 10.2 kg/day for buffalo. The dung produced from cattle and buffalo is estimated as 730 Mt for 2010. The total dung recoverable will be 510 Mt by 2010. Biogas generation from animal manure is not new in India [36]. Anaerobic digestion of the cattle manure has been studied by various people and found to be successful [37–41]. The numbers of family size biogas plants which will utilize the dung are estimated to be 12 million by 2010 and produce a biogas of 3448 Mm^3. If the entire dung recovered is used for biogas production, 17,850 Mm^3 can be produced by 2010 [35].

2.4.5. *Industrial waste*

The waste obtained from various industries differs significantly in terms of chemical composition and quantity and depends on raw material and the chemical process undergone. In this study

Table 7
Chemical characteristics of MSW in Indian cities population wise [32].

Population in range (in million)	Nitrogen as total nitrogen	Phosphorous as P_2O_5	Potassium as K_2O	C/N ratio	Calorific value (kcal/kg)
0.1–0.5	0.71	0.63	0.83	30.94	1009.89
0.5–1.0	0.66	0.56	0.69	21.13	900.61
1.0–2.0	0.64	0.82	0.72	23.68	980.05
2.0–5.0	0.56	0.69	0.78	22.45	907.18
5.0 and above	0.56	0.52	0.52	30.11	800.70

Table 9
Biomass from agricultural waste and crop residue in India [3].

State	Area (kha)	Crop production kt/year	Biomass generation (kt/year)	Biomass surplus (kt/year)
Andhra Pradesh	2540.2	3232.0	8301.7	1172.8
Assam	2633.1	6075.7	6896.3	1398.4
Bihar	5833.1	13,817.8	20,441.8	4286.2
Chattisgarh	3815.5	6142.8	10,123.7	1907.8
Goa	156.3	554.7	827.2	129.9
Gujarat	6512.9	20,627.0	24,164.4	7505.5
Haryana	4890.2	13,520.0	26,160.9	9796.1
Himachal Pradesh	710.3	1329.2	2668.2	988.3
Jammu and Kashmir	368.7	648.7	1198.7	237.7
Jharkhand	1299.8	1509.0	2191.2	567.7
Karnataka	7277.3	38,638.5	23,766.8	6400.6
Kerala	2041.7	9749.7	9420.5	5702.0
Madhya Pradesh	9937.0	14,166.9	26,499.6	8033.3
Maharashtra	15,278.3	51,343.3	36,804.4	11,803.9
Manipur	72.6	159.4	318.8	31.9
Meghalaya	0.8	14.0	42.0	8.4
Nagaland	27.1	87.6	149.2	27.2
Orissa	2436.6	3633.3	5350.4	1163.4
Punjab	6693.5	27,813.7	46,339.8	21,267.0
Rajasthan	12,537.5	93,654.8	204,887.6	35,531.0
Tamil Nadu	2454.0	24,544.6	15,976.6	6658.7
Uttar Pradesh	12,628.2	46,800.8	50,416.7	11,725.9
Uttaranchal	66.4	135.8	159.9	51.6
West Bengal	5575.6	21,062.8	23,316.0	2959.7
Total				27,8710.0

Table 10
Wastewater generation in India [33].

Name of the zone	City classification	Wastewater generated (Mld)	Wastewater collected (Mld)
South	Very big	669.53	
	Big	58.22	
	Medium	640.42	
	Small	1532	
		2911	1812
North	Very big	1935	
	Big	394	
	Medium	948.26	
	Small	2250	
		5578	3932
Western	Very big	978	
	Big	437	
	Medium	780.525	
	Small	1269	
		3469	2275
Eastern	Very big	55	
	Big	297	
	Medium	631	
	Small	2461	
		3434	2151

major industries which are generating biological waste are considered. The industries includes distillery, dairy, pulp and paper, poultry, tannery, slaughter houses, cattle form waste, sugar, maize starch and tapioca starch.

2.4.5.1. Distilleries. The major process wastewater stream from the distillation stages is the 'spentwash' and is regarded as a high strength waste having large potential for generation of biogas using anaerobic digestion [36,42,43] with the following physico-chemical properties. Characteristics of spentwash are given in Table 11 [33]. The values of BOD, COD and solids indicate the potential of biogas and the following baseline data is considered for biogas potential estimation (Table 12). It is estimated that 34,627,395 m^3 of spentwash is produced annually and is available for biogas generation. The total volume of biogas generation potential will be 1,048,393,125 m^3/year [33].

2.4.5.2. Diary plants. The dairy industry is having various operations which includes silo washing, can and crate washing, plant washing, tanker washing, milk processing, other dairy products, etc. involved in waste production [44,45]. The waste generated from each unit operation is different and generally will be mixed before treatment. We have used the base line data for calculating the biogas potential from the diary effluent as per Table 13. The

Table 11
Characteristics of spentwash from distilleries [33].

Parameter	Range
pH	3.0–4.5
Total solids (mg/L)	1,10,000–1,90,000
Total suspended solids (mg/L)	13,000–15,000
Total dissolved solids (mg/L)	90,000–1,50,000
BOD (20 °C, 5 days)	40,000–50,000
COD	90,000–100,000
COD:BOD	2.2–2.5
TKN (as N)	1000–1200
Temperature (°C)	95–98

Table 12
Baseline data for calculating average biogas energy potential of distillery spent wash [33].

Parameter	Value
Annual operating days	300
Spentwash quantity	15 cum/KL
BOD (mg/L)	45,000
COD (mg/L)	1,00,000
BOD removal efficiency (%)	80
COD removal efficiency (%)	65
Biogas methane (%)	60
Biogas quantity (cum/cum spentwash)	25

Table 13
Baseline data for calculating average biogas energy potential of dairy effluent [33,44].

Parameter	Value
Annual operating days	350
BOD (mg/L)	2500
COD (mg/L)	5500
BOD removal efficiency percentage	85
COD removal efficiency percentage	75
Biogas methane (%)	60
Biogas quantity (cum/kg COD removed)	0.5

total biogas generation potential of all the 342 dairy units is estimated to be 219,409 m^3/day [33].

2.4.5.3. *Pulp and paper industry.* Indian Paper Industry is more than a century old and has developed admirably adapting to a wide range of locally available cellulosic fiber resources. The manufacture of paper generates significant quantities of wastewater; as high as 60 m^3/tonne of paper produced. The raw wastewaters from paper and board mills can be potentially very polluting and observed to be having COD as high as 11,000 mg/L [46]. There are about 51 agro based mini and medium capacity mills with a total capacity of 2921 tpd (tons per day). The feasibility of biogas generation from slaughterhouse wastewater has been studied by various people [46–49] and indicated significance. The following base line data is used for estimation of biogas from pulp and paper industry waste (Table 14). The total daily biogas generation potential from the anaerobic treatment of black liquor from all these units will be 412,278 m^3/day [33].

2.4.5.4. *Poultry.* India's poultry industry is the fifth largest in the world in egg production and the fastest growing industrial sector with an annual growth rate of about 16%. Over 50% of the total egg production in India comes from the states of Andhra Pradesh, Maharashtra, Tamil Nadu, Punjab and Haryana. The states of Andhra Pradesh, Maharashtra, Tamil Nadu, Punjab and Karnataka together contribute to more than 50% of the broiler production in the country. At present, there are more than 700 hatcheries and about 10 major poultry processing plants in India. There are three main phases in poultry industry namely production, development and processing which produces wastes such as egg shells, unhatched eggs, poultry droppings, waste feed, etc. [44,50]. The physical composition of fresh poultry manure is given in Table 15. Biogas potential is estimated based on the following baseline data (Table 16). The total biogas potential of all the farms in the country is to be estimated as 438,227 m^3/day. But since the potential of individual farms is not enough to set up an independent energy recovery unit, clustering of farms in the same district can be taken up. The cluster can have a combined energy recovery unit [33].

Table 14
Baseline data for calculating average biogas energy potential of pulp and paper industry effluent [33,46].

Parameter	Value
BOD (mg/L)	4000
BOD:COD	3:1
BOD removal efficiency (%)	80
COD removal efficiency (%)	60
Biogas methane (%)	60
Biogas quantity (m^3/kg COD removed)	0.5

Table 15
Physical composition of fresh poultry manure [33,50].

Parameter	Value
Moisture	75–80%
Volatile solids	15–16%
Ash content	5–7%
Bulk density	1100 kg/cum
Calorific value (based on 75% moisture)	3200 kJ/kg of wet manure

Table 16
Baseline data for calculating average biogas energy potential of poultry manure [33].

Parameter	Value
Poultry litter generated per bird	100 g/bird/day
Moisture content	40%
Volatile solid content	50%
Volatile solids utilized for biogas generation	40%
Biogas produced	0.8 m^3/kg of volatile solids destroyed

2.4.5.5. *Slaughter houses.* The Food Processing Industry sector in India is one of the largest in terms of production, consumption, export and growth prospects. The total meat production in the country is 4.42 Mt, which includes beef, buffalo meat, mutton, goat meat, pork and poultry meat. The various kinds of meat produced in India are shown in Table 17. The country has 3600 slaughter houses, 9 modern abattoirs and 171 meat processing units licensed under meat products order. The major meat production centers are located in Aurangabad, Nanded, Mumbai and Satara in Maharastra, Goa, Medak district in Andhra Pradesh, Derabassi in Punjab, Aligarh, Unnao and Ghaziabad in up and Cochin in Kerala. The basic slaughtering process includes lairage, slaughtering, bleeding, dressing, evisceration and carcass splitting. The water is consumed in the various processes; huge quantum of water is required for washing and for animals during lairage. The quantum of water consumed during slaughtering depends up on the kind of animal slaughtered. The wastewater from the slaughter house is strong in nature, with a COD to BOD ratio of 2 to 2.5. Studies have been carried on the slaughter house wastewater [51–53] and the typical characteristics of wastewater generated from a slaughter house in Rudram are given in Table 18. Biogas potential is estimated based on the baseline data as shown in Table 19. The wastewater generated for the slaughter house is calculated on the basis quantum of buffaloes and sheep slaughtered and processed and estimated as 533,652 m^3/day (366). The biogas potential of the wastewater from the slaughter house is estimated as 1,494,225 m^3/day.

2.4.5.6. *Sugar industries.* India is the second largest producer of sugarcane next to Brazil. Presently, about 4 million hectares of land is under sugarcane cultivation with an average yield of 70 tonnes

Table 17
Meat production in India [33,51].

Meat	Quantity (Mt)
Buffalo/cow meat	2.8
Sheep/goat meat	0.7
Pig meat	0.5
Poultry meat	0.5
Total	4.5

Table 18
Characteristics of slaughter house wastewater [33,51].

Parameter	Value
pH	6.0–7.0
Total solids (mg/L)	6000–8000
BOD (20 °C, 5 days) (mg/L)	3500–4500
COD (mg/L)	6000–8000

Table 19
Baseline data for calculating average biogas energy potential of slaughter houses [33,51].

Parameter	Value
BOD (mg/L)	3750
COD (mg/L)	7000
BOD removal efficiency (%)	85
COD removal efficiency (%)	75
Biogas methane (%)	60
Biogas quantity (m^3/kg of COD removed)	0.5

Table 20
Characteristics of sugar industry wastewater [33,55].

Parameter	Range
Temperature (°C)	30–40
pH	4.5–6
Total dissolve solids (mg/L)	1000–1200
Suspended solids (mg/L)	250–300
BOD (20 °C, 5 days) (mg/L)	1250–2000
COD (mg/L)	2000–3000
COD:BOD	1.5–1.6
Oil and grease (mg/L)	60–100

Table 21
Baseline data for calculating average biogas energy potential for sugar industries [33,55].

Parameter	Value
Combined wastewater	
BOD (mg/L)	1500
COD (mg/L)	2500
COD:BOD	1.6
BOD removal efficiency (%)	85
COD removal efficiency (%)	75
biogas methane (%)	60
Biogas quantity (m^3/kg of COD removed)	0.5
Pressmud	
Moisture content (%)	85
Total solids (%)	15
Volatile solids % TS	70
Volatile solids destroyed (%)	60
Biogas methane (%)	60
Biogas quantity (m^3/kg of VS destroyed)	0.8

per hectare. Since the sugar industry in the country uses only sugarcane as the input, sugar factories have been established in large cane growing states like Uttar Pradesh, Maharashtra, Tamil Nadu, Karnataka, Punjab and Gujarat. Sugar factory operations generate bagasse as a solid waste and other process wastes include wastewater and press mud. The major process wastewater streams from the sugar industry are: milling, cooling water, boiler blow down, sulphur house, lime house and spray pond overflow. The wastewater obtained had been used for anaerobic digestion and produced biogas from it [54,55]. The typical characteristics of combined wastewater from a sugar factory are given in Table 20.

The baseline data which are given in (Table 21) were used for estimating the potential of biogas from industry waste which includes combined wastewater and pressmud. The total quantum of wastewater generated from 431 sugar factories will be up to 534,000 cum/day. 534,000 m^3 of biogas can be generated per day from the digestion of wastewater from the sugar industry. The total biogas generation potential utilizing pressmud obtained from all the 431 sugar factories is estimated to be 2.32 Mm^3/day [33].

3. Conclusions

Biomass is a potentially reliable and renewable energy resource for India because of its availability as agricultural waste, sewage sludge, animal manure and industrial waste. Anaerobic digestion of biomass can be considered as one of the most promising energy carrier for the future generations. Several biomass plants are constructed to convert different forms of wastes into energy and the list is presented as Table 22. The total numbers of family size biogas plants installed as of March 2005 are 3.71 million against 12 million. The need to optimize utilization of India's vast potential for energy generation from biomass and to alleviate the severe power crunch faced by the country requires the integration of bioenergy into the national energy planning thereby enabling the creation of balanced energy mix. This in turn calls for taking bioenergy technologies beyond the stage of research, development and demonstration to commercialization through appropriate financing mechanisms.

Table 22
Summary of biomass plants installed in India, state wise [3].

No	State	Biomass power (MW)
1	Andhra Pradesh	210.20
2	Chattisgarh	146.30
3	Gujarat	0.50
4	Haryana	4.00
5	Karnataka	81.50
6	Madhya Pradesh	1.00
7	Maharashtra	11.50
8	Punjab	16.00
9	Rajasthan	23.30
10	Tamil Nadu	111.50

There exists a significant gap between technical and profitable potential and the realizable potential. A lot of things which may be technically feasible are rejected for various reasons like land scape protection, lack of skilled labour, employment opportunities and some times even social and emotional aspects. In future, additional yield of biomass only be achieved by using those areas that are agriculturally used today. Shell international has published projection for different energy sources for the years 1990–2100 which forecasts that energy consumption will increase 7 times during this period. The international panel on climate change (IPCC) predicts a 3 times higher energy consumption by 2100. On the same lines, world energy council (WEC) in 1995 gave a scenario predicting 4.2-fold increase in energy consumption by 2100. The global picture shows that by 2025, renewable energy related technologies will expectedly reach their potential for toll economic usage. As is well known, economic potential for conversion of hydroelectric power to energy has been extensively used. However all other renewable resources having huge potentials not been fully exploited, and there exists a huge scope for improvement in this area.

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